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### Version of attached file:

Published Version

### Peer-review status of attached file:

Peer-reviewed

### Citation for published item:

Manuel, Mark and Lightfoot, Dale and Fattahi, Morteza (2018) 'The sustainability of ancient water control techniques in Iran : an overview.', *Water history.*, 10 (1). pp. 13-30.

### Further information on publisher's website:

<https://doi.org/10.1007/s12685-017-0200-7>

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# The sustainability of ancient water control techniques in Iran: an overview

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Received: 20 April 2016 / Accepted: 16 May 2017

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**Abstract** *Qanats* are a traditional source of water management that exists throughout much of the Middle East, and extending into North Africa, Spain and South Asia. In particular, they have played an important role in managing the supply of water throughout Iran for over two millennia in what is an arguably a sustainable manner. With water scarcity playing a prominent role in the modern world, *qanats* offer a practical, low cost solution to these issues. This paper looks at the early development of *qanats* in Iran, the important role they played in revolutionising the settlement systems and sustainability of communities in the past, and how they are now being reinvigorated to provide sustainable water in the present in Iran and other countries.

**Keywords** Qanat · Karez · Sustainable irrigation · Water management · Sustainability · Water scarcity · Archaeology

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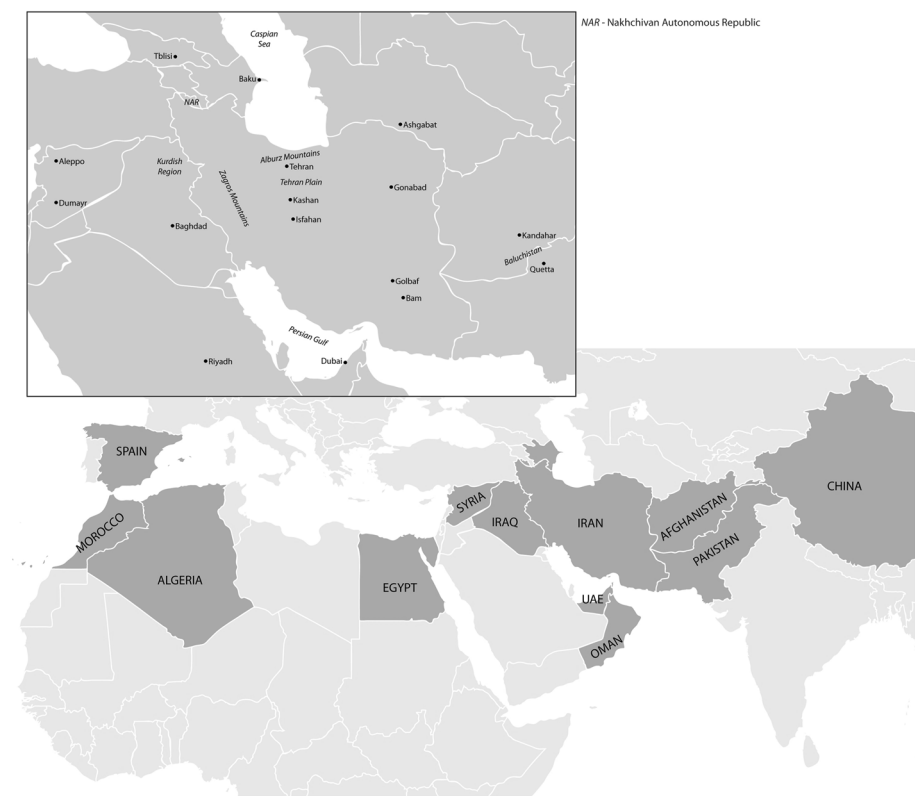
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## Introduction

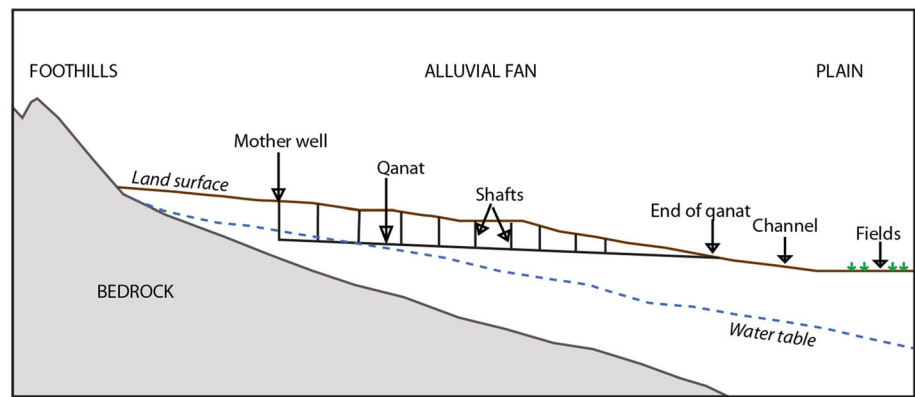
The management of water has had a profound effect on the development of complex societies across the world, from the simple digging of wells to the creation of highly complex networks of irrigation systems. Most early complex societies engaged in some form of water management techniques—from the household wells that characterise early cities in the Indus Valley c.2500 BC (Jansen 1991, pp. 147–160), to the annual capture of inundation waters along the Nile Valley (Hassan 1997). Indeed, it was seen as one of the primary drivers of early state formation, and often as part of a centralised and autocratic or despotic political arrangement (Wittfogel 1956, 1957). More recently, the development and ongoing management of water and irrigation systems can be seen as part of collaborative and co-operative social activities that help bind communities within the wider landscape. One example of this can be seen in Early Historic Sri Lanka, where hundreds of kilometres of canals and almost 30,000 tanks or reservoirs were created, enlarged and maintained by a sequence of kings and rulers (Brohier 1934). This complex hydraulic system was designed to capture and store the winter monsoon rains, and ensure the water remained accessible throughout the year. This endeavour enabled the agricultural carrying capacity of North Central Province to increase from 0.4 individuals, to 2400 per km<sup>2</sup> (Coningham 1999, p. 24). Whilst largely abandoned from the 11–14th centuries AD onwards (Gilliland et al. 2013), the hydraulic network was reinvigorated by the British in the 19th and 20th centuries AD in order to repopulate the area (Brohier 2006 [1975], pp. 75–79). Six years of research at Anuradhapura suggests that the ongoing management of these hydraulic systems was not the job of the ruling kings who created them, but instead was devolved to monastic institutions in the hinterland (Coningham et al. 2013). Similar decentralised hydraulic management models exist within the water temple systems of Bali, where irrigation and the control of water is placed in the hands of farmer associations or *subaks* (Lansing 1987, p. 326).

*Qanats* are a traditional source of water management that exists throughout much of the Middle East, and extending into North Africa, Spain and South Asia (Fig. 1). Essentially they are subterranean tunnels excavated in order to transport large volumes of water from springs or water sources in upland areas to the dry, arid plains below. While seeming relatively simple, these tunnels can extend for tens of kilometres and require careful planning and construction (Beaumont 1968, 1971). The *qanat* tunnel is excavated from the base or outlet upwards into the area of water source—the mother well. During this process, vertical shafts are dug to provide ventilation and access for the immediate removal of spoil, and later on for cleaning (Fig. 2). The spoil from these access shafts creates the distinctive doughnut-shaped rings that characterise *qanat* lines. *Qanats* were in use by the start of the first millennium BC and archaeological studies report dates of 300–1000 BC for the earliest *qanats* in the UAE, Oman, and Iran (Labba Khaneiki 2000, Magee 2005, Al Tikriti 2002). Although OSL dating suggests that the oldest known *qanat* was constructed 2000 BC (Fattahi et al. 2014), still the exact date of the earliest *qanats* is unknown (see chapter in this volume for more on dating *qanats*). Within the arid and semi-arid regions of Iran they were the major source of perennial water until the mid-twentieth century when they became increasingly less important with the advent of modern engineering projects and, in particular, the advent of motorised pumping allowing access to deeper water sources (Beaumont 1968, p. 177).

With water scarcity highlighted as one of the leading issues facing the world in the future and Iran listed as “approaching physical water scarcity”, focusing on issues of water



**Fig. 1** Map of countries containing *qanats* as mentioned in the text, and the location of more specific case studies



**Fig. 2** Schematic of how a *qanat* transports water from upland to lowland areas (after Beaumont 1968, p. 171)

management in the past and questions of sustainability are paramount (WWAP 2012; Manuel et al. 2014). *Qanats* offer a practical solution to problems of water supply due to their low evaporation rates during delivery and the relatively low cost and level of technology. Despite new irrigation projects, qanats have remained in service because they are, in most circumstances, sustainable—they can be used in perpetuity without damage to the environment, with limited depletion of the inputs on which it depends, or disruption to the socio-economic systems that maintain it. They deliver water through the force of gravity and do not require a source of power or fuel to operate. *Qanat* use encourages recycling and re-use of water at various stages along the linear system and *qanats* can only drain water from an aquifer that is naturally recharged; they do not pump water from an aquifer or draw down the water table. Because they do not reduce the capacity of an aquifer to retain water, they do not contribute to the compaction of aquifers and resulting surface subsidence and soil compaction as many pumped technologies have done. Furthermore, the social and economic systems that have maintained *qanats* for many centuries are aided by the social contracts and structures required to keep qanats healthy.

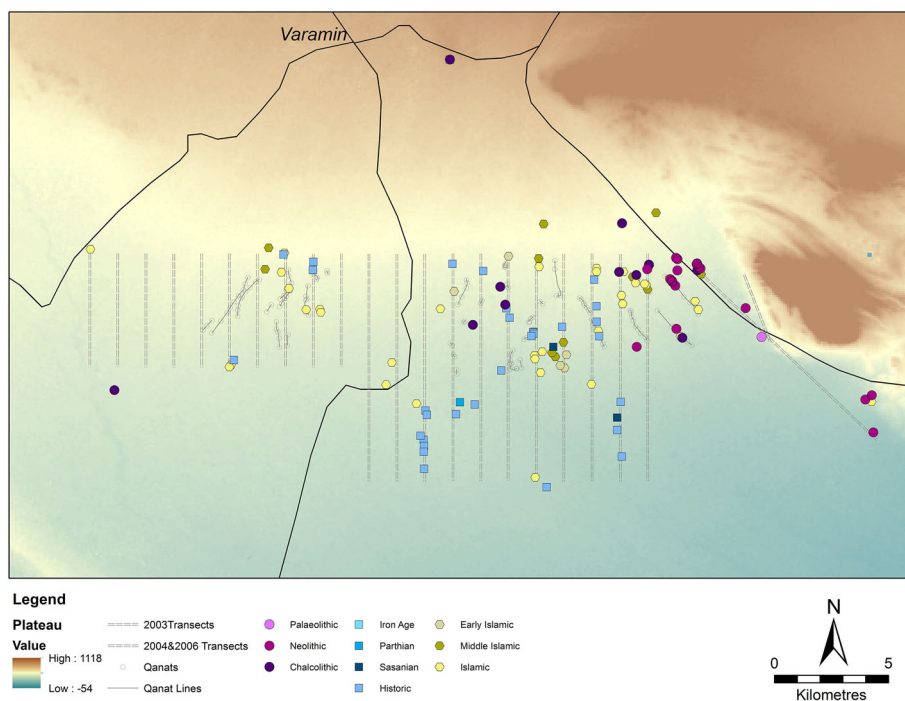
This paper looks at the early development of *qanats* in Iran, the important role they played in revolutionising the settlement systems and sustainability of communities in the past, and how they are now being reinvigorated to provide sustainable water in the present in Iran and other countries.

## **Qanats as sustainable water management techniques in the Central Plateau**

The Central Plateau of Iran is a semi-arid desert surrounded by the Zagros Mountains to the west, the Alburz Mountains to the north, and by the upland areas of Baluchistan to the south and east. It incorporates the modern cities of Tehran, Qom, Isfahan and Kashan, as well as the low-lying salt plains of the Dasht-i-Kavir. Rainfall is seasonal predominantly falling between December and March, with averages between 220 and 340 mm at Tehran and Kashan (Ganji 1968, pp. 243–245). During these periods of rainfall and the subsequent snowmelt from the surrounding mountains, the alluvial fans within the Central Plateau become very fertile. However, during the harsh summer months, where rainfall is non-existent and temperatures can regularly exceed 45 °C, agriculture is not possible without artificial irrigation.

This stark seasonality has been a driving force behind the development of complex societies within the Central Plateau, and the Tehran Plain in particular. The earliest evidence of settled communities in the area is found within the upland areas surrounding the Plateau—at sites such as Ganj Dareh, Ali Kosh and Choga Bonut—at around 8000 BC (Hole 2004). Several years of archaeological survey within the Tehran and Varamin Plains have demonstrated that the expansion or movement of communities from the upland and piedmont areas to the plain itself was a slow process (Fig. 3). By the Neolithic (6000–5200 BC) and Chalcolithic period (5200–3400 BC) a small number of settlements were established on the alluvial fan of the Jajerud River—one of the few that flows all year round—or, as in the case of Cheshmeh Ali, next to natural springs (Fig. 4) (Fazeli et al. 2004). Many of these sites show clear evidence of intermittent occupation, and the suggestion is that early communities shifted as did water courses (Manuel et al. 2014).

What is clear is that one of the major constraints on early settlement on the Tehran Plain was access to perennial water sources. Indeed, Roman Ghirshman, one of the early



**Fig. 3** Maps showing the development of settlement in Tehran Plain to the south of the modern city of Varamin from the Palaeolithic through to the Islamic period. Note how settlement is clustered along the junction of hill and plain at first, before expanding into the desert with the advent of *qanat* technology. (Topographic data is from NASA SRTM, and survey data is from the Tehran Plains Survey Project)



**Fig. 4** The natural spring at Cheshmeh Ali, which is now a public park, demonstrates the importance of water to the location of early settlements in the Tehran Plain (photo by Robin Coningham)

archaeologists who studied the Central Plateau of Iran, and excavator of Sialk and Cheshmeh Ali, stated that, “the physical aspects of the Plateau was harsh and austere. The oases were dispersed over difficult country, the population was sparse and scattered. As a result the urban revolution was retarded, and society continued in its prehistoric stage for centuries” (1954, p. 42). Excavation at Tepe Pardis has demonstrated the presence of a Neolithic (radiocarbon dated to 5220–4990 BC) irrigation channel, alongside evidence of shifting river channels running past the site (Fazeli et al. 2007; Gillmore et al. 2009). This early adaptation of the landscape to provide irrigation highlights the importance of water in sustaining settlements in the Central Plateau. However, Ghirshman’s statement strikes a resonance, in that settlement in the area was heavily restricted until about 3000 years ago.

The situation changed with the introduction of *qanat* technology c.1000 BC which revolutionised people’s ability to survive and subsist within the Central Plateau. By the mid-first millennium BC, during the Parthian and Sasanian period, settlement had dispersed across the plain and was no longer restricted by the shifting of water courses (Fazeli et al. 2007). However, many of the sites dating to this phase lacked key artefactual indicators associated with Sasanian or Parthian occupation elsewhere, suggesting that imperial presence in the area was weak, and that *qanat* construction was very much a localised prerogative. The near perennial flow of water provided by *qanats* allowed communities to concentrate population in one area and to open up larger tracts of land for agriculture (Manuel et al. 2014, pp. 57–58). Essentially, *qanat* technology reduced the impact of the Plateau’s stark seasonality, allowing for sustainable occupation of the plains, and to utilise the rich alluvial soils. Some of the larger sites, such as Kaleh Navid, had several *qanat* lines terminating close to the village, and testify to the importance of water access. Indeed, population in the Central Plateau has boomed since its initial occupation, and is now home to some of Iran’s major urban centres and agricultural regions.

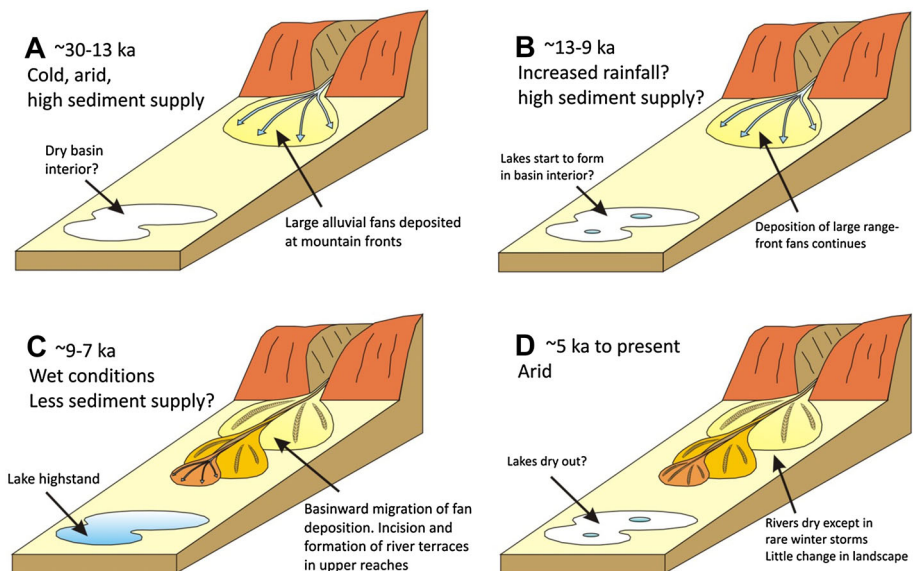
*Qanats* are present throughout all of Iran, and some estimate that there are 22,000 functioning *qanats* transporting water for over 270,000 km of underground tunnels (Mostafaiepour 2010, p. 63), whilst other estimates place the number of *qanats* as high as 36,000 (Semsar Yazdi and Labbaf Khaneiki 2012b). The longest is at Gonabad in north-eastern Iran, where a *qanat* extends for over 70 km in length, and transports water from a mother well sunk to a depth of 400 m (*ibid.*). Whilst this represents a huge investment in construction, and perhaps management, the majority of *qanats* in Iran are of a much smaller scale. Wilkinson et al. (2012) argue that most *qanats* are roughly 5–10 km in length, and that their origins are likely to be determined by local necessity as opposed to imperial or elite intervention (2012, pp. 169–170). In the Varamin Plain a study of 266 *qanats* showed lengths that varied between two and five kilometres in length, with the longer *qanats* at the desert margins (Beaumont 1968, pp. 172–175). Of the 266 *qanats* studied in the Plain, most were concentrated within the central part of the plain, where agriculture was concentrated, and scarcer along the alluvial cone and desert margins. Each village had access to only one *qanat*, with the exception of four villages (out of 250) which had access to two (*ibid.*: 172). Indeed, *qanat* lines, both active and defunct, can be seen converging on most Iranian villages, cities and towns, and highlight the importance that *qanats* played in creating the landscape of Iran today. Around the city of Bam there are an estimated 375 *qanats*, stretching 15 km from the city, with individual *qanats* running for up to 10 km in length. Before the 2003 earthquake they played a significant role in providing water to the city. Recognising the importance of *qanats* in sustainable water management, as well as a component of the regions social and cultural heritage, their rehabilitation was considered an important facet of post-disaster responses to the earthquake (Honari et al. 2006). As we will see later, this is being mirrored elsewhere in Iran,



and further afield, as communities seek to re-engage with traditional and sustainable methods.

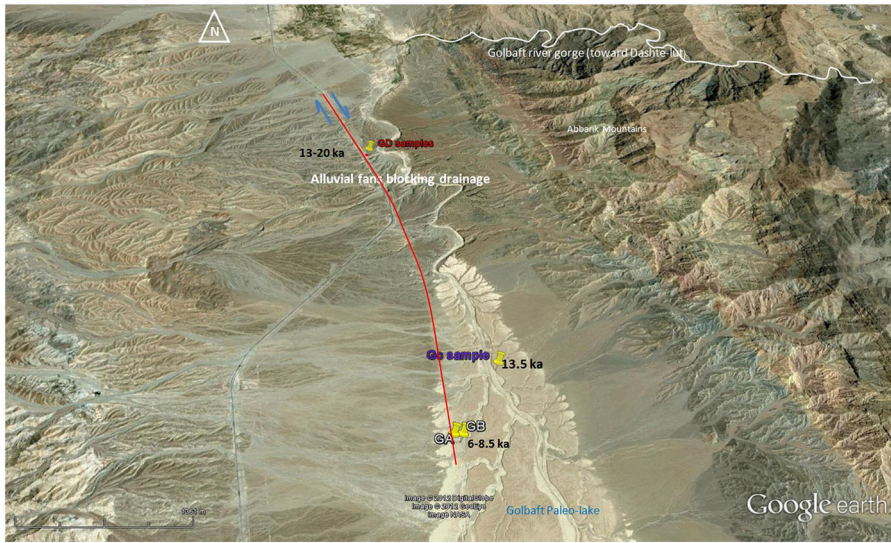
## The long-term use and reinvigoration of qanats

Optically Stimulated Luminescence (OSL) dating of basin sediments in parts of Iran demonstrates that substantial amounts of surface water and heightened precipitation existed in areas that are now considered to be arid. Fieldwork at Dasht-e-Bayaz in the Nimbluk Valley in northeast Iran indicate lake highstand conditions at  $<8.5 \pm 1.1$  ka ( $\sim 6500$  BC) (Fattahi et al. 2010); and the South Golbaf palaeo-lake in southeast Iran indicates lake deposition was ongoing from at least 13.5 ka (11150 BC) until the mid-Holocene (Figs. 5, 6). The South Golbaf palaeo-lake is likely to have spilled into the neighbouring Golbaf basin at  $6.3 \pm 0.2$  ka (4500–4100 BC) (Walker et al. 2010; Fattahi et al. 2014). In general, this moister climate corresponds with a peak in moisture at 7.5 ka (5500 BC) in the eastern Mediterranean (e.g. Bar-Matthews et al. 2003), and followed by gradually increasing aridity, with prolonged droughts at 5.2 and 4.2 ka (3200 and 2200



**Fig. 5** A summary of the Last Glacial and Holocene palaeo-environmental changes suggested by the available age data in eastern Iran. **a** The deposition of large alluvial fans along the mountain range-fronts is likely to have started during the late glacial period with the production of large amounts of sediment in the cold and arid environment. **b** The range front fan deposition appears to have continued into the earliest part of the Holocene. The widespread fan deposition may be accompanied by an increase in the amount of precipitation combined with a plentiful supply of sediment. **c** The period from  $\sim 9$  ka through to at least  $\sim 7$  ka is marked by high lake levels indicating a relatively wet environment. Alluvial fan deposits at the mountain range-fronts are abandoned and incised due to a basinward migration of river-borne sediment deposition. The switch from sediment deposition to incision at the range-fronts may be a response to elevated rainfall coupled with a decreasing supply of sediment. **d** From the mid-Holocene it appears that river incision has slowed and the landscape has achieved roughly the form that it takes today. The slowing of landscape evolution may result from the onset of the arid climatic conditions that continue through to the present day (From Walker and Fattahi 2011)





**Fig. 6** The Golbaf basin in central Iran held substantial amounts of water from at least 13.5 ka through ~6.3 ka, as indicated by the thick homogeneous silt beds observed in exposures of sediment from the palaeolake interior (From Fattahi et al. 2014: Fig. 6)

BC). The latter of these droughts coincides with the collapse of the Akkadian Empire in Mesopotamia (Weiss et al. 1993; Cullen et al. 2000; deMenocal 2001), although this was in no means the primary driver of societal collapse (Wossink 2009).

Walker and Fattahi (2011) have suggested that increased aridity slowed the evolution of the landscape and had a detrimental effect on Bronze Age societies in eastern Iran. This mirrored a decline in a number of complex agricultural societies around the eastern Mediterranean and North African regions (e.g. Hassan and Stucki 1987; Weiss 2000; deMenocal 2001; Staubwasser and Weiss 2006). A scenario of regional aridification in the mid- to late Holocene is suggested by archaeological studies from southeast Iran (Adle 2006; Fouache et al. 2008). Lawler (2011) has suggested that Shahr-i Sokhta in southeast Iran was abandoned c.3000 BC after the Helmand Delta dried up and changed course. Excavations at Bam, a Bronze Age, predominantly agrarian, settlement twice as large as Shahr-i Sokhta, collapsed towards the end of the 3rd Millennium BC (Walker and Fattahi 2011). Following these urban abandonments people migrated to new places with access to surface water or springs. Adler (2006) and Fouache et al. (2008) argue that it was people in those areas where surface water was not readily available that spearheaded the development of *qanat* irrigation technology in order to re-establish agricultural societies some 1000 years later. The oldest absolute date for *qanat* construction suggest that this system was in use around 2000 BC in Dashtebayza, in northeast Iran (Fattahi 2015). A potential reason for a shift in the use of surface canals to *qanat* irrigation in the early part of the Archaemenid period (2.5 ka/500 BC) at archaeological sites excavated near Sabzevar is attributed to a decrease in the availability of surface water (Fouache et al. 2010; Fig. 2) (Adle 2006; Fouache et al. 2008).

In the course of history the knowledge of *qanat* construction kept evolving. According to Semsar Yazdi and Askarzadeh (2007a) and Semsar Yazdi (2007b), it was an Achaemenid (550–330 BC) ruling that in case someone succeeded in constructing a *qanat* and

bringing groundwater to the surface in order to cultivate, or renovating an abandoned *qanat*, the tax they were supposed to pay the government would be waived not only for themselves but also for up to five successive generations. Conversely, during the Seleucid (312–250 BC) and Parthian era (250 BC–AD 150) little imperial attention was paid towards *qanats*. During the Sassanid era (AD 226–650), the government supported the repair and construction of new *qanats*. *Qanats* continued to be utilised after the arrival of Islam (AD 621–1921), however, the invasion of Mongolian tribes in 13th century saw many *qanats* and irrigation systems fall into ruin. In the Safavid era (15th and 16th century) many new *qanats*, bridges, dams and water reservoirs were constructed; and the period of the Qajars (16th–18th century) is seen as the heyday of *qanats*. Tehran had a rich supply of groundwater and many *qanats* were constructed in Tehran, and *qanat* construction was supported throughout the country. However, at that time most of the *qanats* of the country belonged to landlords. Feudalism was the prevailing system in the rural regions, and peasants were not entitled to own lands they worked on. They had to pay rent for use of the land and water to the feudal lords. This allowed the feudal landlords to finance the high costs of maintaining *qanats*.

During the Pahlavi period (1925–1979), the process of *qanat* construction and maintenance continued. In 1959 a reformative program named the White Revolution was declared by the former Shah. One element of this was land reform, allowing individual farmers to obtain ownership of land from their feudal landlords. However, the lack of concentrated finances resulted in the lack of upkeep and maintenance, and many of the *qanats* fell into disrepair. Furthermore, pumped wells had a negative impact on the *qanats* due to their overexploitation of the groundwater, and many *qanats* vanished forever.

In 1963 the Ministry of Water and Electricity (later renamed Ministry of Energy) was established in order to build dams and provide rural and urban areas of the country with sufficient water and electricity. At this period, the executive procedures of 19 dams began, out of which 13 came into action. In 1966 the parliament passed a law protecting groundwater resources, in which the Ministry of Water and Electricity was allowed to ban the drilling of deep and semi-deep wells wherever surveys show that the water table is dropping because of overpumping. This law, as well as the law of water nationalization that was approved in 1968 and eventually the law of fair distribution of water (passed in 1981 after the Islamic Revolution) finalised the definition of restricted and free areas for drilling. In restricted areas the drilling of wells (except for drinking and industry) was prohibited in order to prevent the continuous depletion of groundwater. As a result, *qanats* had a better chance to survive. After 1979, the Islamic Republic of Iran focused on the subject of the management of the surface and ground water. The provision for new 152 dams was identified, of which 72 came into action by 2005. The Jihad Sazandegi Organisation took responsibility for *qanats* and began to provide the users of *qanats* with funding for development. In 2000, an International Conference on *qanats* was held in Yazd to draw attention to *qanats* and *qanat* technology, and led to the creation of the International Center on *Qanats* and Historic Hydraulic Structures in Yazd and the establishment of the *Qanat* College in Taft.

Throughout the history of Iran, *qanats* played a critical role in the economy and socio political structures of the region both in urban and rural areas. Any negative impact on *qanat* systems could be recovered as soon as the crisis was over, but the present risks to *qanats* are huge. The over exploitation of groundwater resources can damage aquifers and surface sediments that cannot be easily recovered.

## Reinvigorating Qanats as modern sustainable water management

There are many more qanats in Iran than in any other country in the world, though many of the same challenges to qanat maintenance and sustainability have been faced by qanats and qanat users elsewhere. Throughout the broader region, *qanat* galleries have dried up, been damaged, or were abandoned through neglect, new channels have been added to regional inventories and there are several countries in the world where *qanats* are still an important part of local and regional water inventories managed by farmers, villages, and national ministries of water and irrigation. This is especially true in Iran, which has more *qanats* and more functioning qanats than any country in the world, and where exists the greatest variety of length, depth, form and features associated with *qanats* (cisterns, sluice gates, wind tunnels, cooling systems and water mills).

Because of their great utility, longevity, and sustainability, *qanats* have been refurbished and used for many centuries by private landowners and village cooperatives; by those who maintain water rights to a *qanat*. In spite of these advantages, *qanats* have often been viewed as backward and inefficient in comparison to modern solutions for water supply. Although they cannot keep pace with the needs of rapidly growing populations and industries, and they are sometimes abandoned in the rush to install newer equipment that can meet these growing needs, *qanats* are actively maintained in several countries to augment water supplies. This applies not only to Iran but to many settlements in Morocco, Algeria, northern Iraq and south-western India, and most notably in Oman, Afghanistan, Pakistan, China, Azerbaijan, where *qanats* are still widely employed as the primary or only source of irrigation and drinking water (Lightfoot, [in press](#)). Many governments in this group maintain lists of *qanats* as part of their national water and irrigation inventories and have funded qanat refurbishment programs or offered loans to private owners or village cooperatives to clean and maintain their *qanats*. In addition to these domestic efforts, many international organizations have orchestrated and funded qanat refurbishment. These programs usually involve surveys to assess a regional system of *qanats* and a refurbishment program to clean and rehabilitate select qanats.

As both a catalyst and consequence of these activities, many specialised conferences and workshops have been held over the past decade bringing together scholars and planners interested in the history and utility of *qanats*, and engineers and *qanat* specialists involved in cleaning and refurbishing *qanats*. New museums and training centres for the promotion and maintenance of *qanats* have also been established in China, Morocco, Azerbaijan, and Iran. In some of these cases, *qanat* inventory and refurbishment have been aided by groundwater modelling and geographic information systems (GIS), which are also used for continuing efforts to manage the water resources of a region (Ansari 2013; Khayyat 2009; Strikker et al. 2013). These national and international efforts in the inventory, promotion, and study of qanats have led to coordinated programs of *qanat* refurbishment in Morocco, Syria, Pakistan, Afghanistan, Azerbaijan, Iraq, and Iran.

A 1992 survey of qanats in the Tafilalt Oasis of southeastern Morocco counted 80 *qanats* constructed to provision 28 villages; yet only 19 of these channels were still flowing at the time of the survey (Lightfoot 1996a). Since that time, collaborative efforts by local cooperatives, NGOs and international groups like the Spanish Centro de Estudios Rurales y de Agricultura Internacional (CERAI) and the Japan International Cooperation Agency (JICA) have directed funding and labour toward the rehabilitation of the disused *qanats* around the oasis (Fig. 7).



**Fig. 7** *Qanat* (khetlara) refurbishment promotion in Morocco

A survey of *qanats* across Syria was completed during 1993–1994 that documented 239 *qanats* across the country, 92% of which had ceased following since the introduction of pumped tube wells (Lightfoot 1996b). Guided by this survey, and using lessons learned during refurbishment of a *qanat* east of Aleppo in 2000, a Dutch scholar located 30 *qanats* in 2001 that were still in use, and targeted *qanats* in Shallalah Saghira, southeast of Aleppo, and Dumayr, east of Damascas for refurbishment. With funding from the Directorate General for International Cooperation and Ministry of Foreign Affairs of the Netherlands and the Swiss Development Cooperation Fund this team guided refurbishment efforts in 2001–2002 and produced a book from this experience that includes best practices in the design and implementation of refurbishment efforts (Wessels 2008).

In Pakistan the majority of *qanats* are found in Baluchistan, with over 800 recorded, and 60–80 percent of these in working condition (Chaudhry 2002; Kahlown 2012). Although most of these have been maintained by individuals and groups with water rights to the *qanats*, nearly 200 have been refurbished since the late 1980s. Collaborations between government ministries, the National Rural Support Programme (NRSP), U.S. Agency for International Development (USAID) and other NGOs aimed to clean *qanat* tunnels, cap *qanat* wells, and extend *qanat* channels and wells to tap deeper aquifers and thereby enhance water flow (Hussain et al. 2008; Kahlown 2012).

In Afghanistan, many of the 9370 *qanats* reported in a FAO/Ministry of Irrigation, Water Resources, and Environment survey were abandoned in historic times, though almost 6000 remained active at the time of this 2003 survey (Shobair 2012). Many have been damaged and abandoned since the 1970s as a result of groundwater pumping and episodic conflict in the country. New laws have been enacted in recent years to protect *qanats* by restricting deep wells and any structure that can damage a *qanat* (Shobair 2012). Several *qanat* refurbishment projects have been funded and managed through the cooperation of the Afghanistan government and NGOs. These programs have focused on survey and strategic planning, and cleaning and repairing select *qanats*. More than 20% of the *qanats* in Afghanistan have benefitted from donor agencies (Shobair 2012).

Almost half of the 885 *qanats* still operating in Azerbaijan are found in the Nakhchivan Autonomous Republic, an exclave territory in the southwest of the country. Many of these began to dry up after 1960 because of negligence and the number of active *qanats* in Nakhchivan dropped to 288 until the International Organization for Migration (IOM)

implemented a program to rehabilitate *qanats* in 2004, working with local government and stakeholders to survey and rehabilitate them (Semsar Yazdi and Labbaf Khaneiki 2012a). By 2011, IOM had rehabilitated 143 *qanats* in Nakhchivan with the help of local stakeholders and funding from the United Nations Development Programme (UNDP), European Commission (EC), Canada International Development Agency (CIDA), Swiss Agency for Development and Cooperation (SDC), and the U.S. State Department. This program was also aided by qanat specialists from UNESCO's International Centre on Qanats and Historic Hydraulic Structures who worked to incorporate modern methods and materials developed in their centre and associated *Qanat* College, and to expand, reinforce and waterproof these qanats (Semsar Yazdi and Labbaf Khaneiki 2012a). The IOM also began a *qanat* rehabilitation project in 2010 designed to renovate 20 *qanats* in the main part of Azerbaijan, with funding from the Korea International Cooperation Agency (IOM 2010; Lucie Dupertuis (IOM), personal communication). At the same time as these international efforts were underway, a new *qanat* was constructed for 90 households of Shishtebe village in Azerbaijan, funded by local water users and wealthy villagers living abroad and assisted with technical advice from IOM specialists (Lenk and Mehdiyev 2013).

UNESCO Iraq's science team has been working with local government authorities and community members to improve the supply of drinking and irrigation water in northern Iraq by helping restore traditional water systems in rural communities and providing training for sustainable water management (McHugh 2012). By 2007 UNESCO was aware that many *qanats* in northern Iraq were drying up and being abandoned and this was contributing to the de-population of villages where alternate sources of water were unreliable, too expensive, or non-existent. A field survey covering the three northern (Kurdish) governorates in Iraq was completed in 2009 under the auspices of UNESCO and documented 683 *qanats*; although 116 were still being used at the time of the survey, almost 70% of the *qanats* still functioning in 2004 had been abandoned since the onset of drought in 2005 (Lightfoot 2009) (Fig. 8). In 2010, armed with details from the survey, UNESCO teamed up with IOM (International Organization for Migration) and together they embarked on a two-year program of *qanat* refurbishment, targeting 22 *qanats* for



**Fig. 8** Chain of wells of an abandoned *qanat* in Iraqi Kurdistan



rehabilitation. Existing *qanat* tunnels were cleaned and, in some cases, new tunnels were extended further into the aquifers to enhance flow. New tunnel casing materials were added to reduce erosion and improve *qanat* performance. New features were also added to many *qanats* to make maintenance easier and to improve water supply, including new well casings, new outflow tunnels and canals, and new water taps and storage basins. On average, water discharge at *qanats* rehabilitated by UNESCO/IOM increased more than 60%, and every community reported that the quality of water improved after rehabilitation (Walther 2011). As a result of these efforts, more than 1000 families have sufficient water to maintain their livelihoods (Fig. 9). In many cases, local people were hired to do much of the work and communities were trained in managing and refurbishing their *qanats* to ensure the sustainable flow of water (McHugh 2012).

Iran maintains more than 36,000 flowing *qanats* (Semsar Yazdi and Labbaf Khaneiki 2012b), far more than the combined 13,000 active *qanats* found elsewhere in the world, and greater even than the total number of *qanats*—fewer than 30,000 (mostly) relic features—found in the other 48 countries where they are known to exist (Lightfoot, *in press*).

For many centuries the *moghani* water specialists have preserved a specialized and valued trade in the construction and maintenance of tens of thousands of *qanats* in the region. With such a great number of *qanats* contributing so much to the national water supply, Iran maintains a long history of enacting laws that protect *qanats* and diverting



**Fig. 9** Exit of the Kani Jinan qanat after restoration, Garazel, Iraq (photo by Lucie Dupertuis)

national income to maintenance and refurbishment. Since the introduction of laws protecting against groundwater pumping in the 1960s, and the national workshops in the 1980s (Semsar Yazdi and Labbaf Khaneiki 2012c), 8000 *qanats* have been rehabilitated in Iran, representing almost 25% of those flowing today (Hussain et al. 2008). These domestic efforts have been aided through international collaborations between the government of Iran and UNESCO, which created the International Centre on *Qanats* and Historic Hydraulic Structures (ICQHS) in 2005. This active centre, with its affiliated *Qanat* College, has collected and disseminated information on *qanats* in the region and worldwide, sponsored research, preserved traditional knowledge, and trained a new corpus of workers on the use of new materials and techniques that are appropriate to maintaining and refurbishing *qanats*. ICQHS specialists are working not only to rehabilitate *qanats* in Iran, but have also organized and hosted a number of international conferences and training workshops and have sent specialists to aid *qanat* rehabilitation projects in neighbouring countries like Azerbaijan and Iraq. *Qanat*-irrigated agriculture in Kashan, in Isfahan Province, Iran has also been the focus of United Nations Food and Agriculture Organization preservation efforts (for water and tourism) since 2013 as part of their Conservation and Sustainable Management of Globally Important Indigenous Agricultural Heritage Systems (GIAHS) program (UNFAO 2014).

## Discussion and Conclusion

Tens of thousands of *qanats* have been engineered, excavated, and maintained for centuries to augment water supplies from springs and wells and to bring a flowing stream of surface water to places that had no flowing water. *Qanats* remain important in several countries, even after many centuries of use, because they require little technology to operate and they are sustainable systems that have lasted. Nowhere have they been built in greater numbers, or maintained with such regularity, than in Iran, where emerged a dedicated class of labourers—the *moghani*—who trained others through the generations as skilled *qanat* builders to maintain the *qanats* of Persia and to expand this technology to surrounding regions. This symbiotic system of skilled labour and long-lived technology was made possible by the sustainability of the whole *qanat* enterprise.

Although *qanats* operate in a sustainable manner with their environment, they have been damaged and abandoned over the centuries as a result of earthquakes, droughts, wars, and social and technological changes that alter the labour supply; multiple factors that have impacted the socio-environmental context of the *qanat* system. In the modern era, it was the introduction of diesel and electrically-powered tube wells that has had the most immediate and adverse impact on the longevity of *qanats*. A *qanat* is only sustainable as long as the aquifer on which it depends is in balance. Pumped wells commonly withdraw more water from an aquifer than is naturally resupplied, resulting in falling water tables and *qanats* that are insufficiently supplied from their source wells. This, combined with long-term drought, can result in the abandonment of *qanats*, as we have seen in many parts of Iran and the broader region over the past decades.

As water scarcity becomes an increasingly pressing issue within the modern world, the reinvigoration of *qanats* can play an important role in supporting the sustainable use of water across what is a climatically, and often politically, unstable region. The relative simplicity of construction and management of the systems ensures that local communities can retain ownership of them. Increasing awareness of the role they can play is also clear



from United Nations initiatives, and the creation of institutions such as the ICQHS and *Qanat* College in Iran. *Qanat* reinvigoration can act as a champion for other traditional water and resource management strategies globally. Furthering our archaeological understanding of *qanats* is also helping us to elucidate the date of origin, how they transformed the sometimes hostile landscapes of Iran and its neighbouring countries and how they can revitalise communities that reside there in the present day.

**Acknowledgements** The authors would like to express their gratitude to Julien Charbonnier and Kristen Hopper for organising *The Qanat: Archaeology and Environment* workshop at Durham University in October 2014, and for inviting us to contribute towards this special edition. Thanks also go to Durham University, the British Institute of Persian Studies and the British Foundation for the Study of Arabia for supporting the workshop. We would also like to thank the following people and institutions for their support in conducting fieldwork and research into the archaeology, geography and restoration of *qanats*: UNESCO, the International Organization for Migration, the British Institute of Persian Studies, the Iranian Cultural Heritage, Handicrafts and Tourism Organisation (ICHHTO), the Iranian Centre for Archaeological Research, the Sialk Archaeological Research Centre, the British Academy, the Institute of Geophysics and the Institute of Archaeology of the University of Tehran, Professor Robin Coningham, Professor Hassan Fazeli, Professor Gavin Gillmore, Professor Ian Simpson, Dr Ruth Young, Armineh Marghussian, Hingameh Ilkhani, Hossein Azizi, Dr Sayyed Taha Hasehmi, Dr Mohammad Gholam Nejad, Dr Seyed Mahdi Mousavi Koohpar, Dr Hassan Karimian, Dr Hayedeh Laleh, Dr Masoud Azarnoush, Dr Richard Walker, Dr Mohammad M Khatib, Dr Morteza Talebian, Professor Majid Nabi-Bidhendi, Casey Walther, Dr Idris Hadi, Dr Beriwan Khailany, Hawta Khatyyat, Lucie Dupertuis and Dr Randy Donahue.

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